

# OPERA superluminal neutrinos explained by spontaneous emission and stimulated absorption.

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In this work it is shown, that for short  $3ns$  neutrino pulses reported by OPERA, a relativistic shape deforming effect of the neutrino distribution function due to spontaneous emission, produces an earlier arrival of  $65.8ns$  in agreement with the reported  $62.1ns \pm 3.7ns$ , with a RMS of  $16.4ns$  explaining the apparent superluminal effect. It is also shown, that early arrival of long  $10500ns$  neutrinos pulse to Gran Sasso, by  $57.8ns$  with respect to the speed of light, could be explained by a shape deforming effect due to a combination of stimulated absorption and spontaneous emission, while traveling by the decay tunnel that acts as a LASER tube.

## I. INTRODUCTION

Recently, OPERA collaboration has reported 20 superluminal neutrinos coming from  $3ns$  LHC extractions, in addition to the 16000 neutrinos, collected for 3 years coming from  $10500ns$  LHC extractions [1] that apparently are faster than light for  $\approx 60ns$  while traveling 730 km from CERN to Gran Sasso National Laboratory. What is most amazing is that the velocity obtained is even faster than the known speed of light in the vacuum, within margins of error accurately calculated. This result is in direct contradiction with Einstein's Relativity Theory that has been the angular corner of modern physics for more than a century. The speed of light in vacuum is considered to be the limit velocity for all matter and information travel, as a consequence of the causality principle.

OPERA faster than light neutrinos is in direct contradiction with astronomical observations as the SuperNova 1987A [2]: in 1987 three independent neutrino observatories: *Kamiokande II* in Japan, *IMB* in USA, and *Baksan* in the former USSR detected 11, 8 and 5 neutrino events, in a burst lasting less than  $13s$  almost at the same UTC time. Approximately three hours later the light from the Nova was observed. This does not indicate that neutrinos arrived faster than light, the accepted explanation is that neutrinos arise from the collapse of the star core, but the burst of light occurs only when the shock waves reach the star surface. If OPERA result is right, the neutrinos must precede the light by  $60ns$  for each  $730km$ , as the Nova 1987A is 168.000 light year away from the earth, neutrinos must arrived earth 1500 days BEFORE the explosion was observed, an not few hours earlier.

Even recently, it has been argued that superluminal neutrino will decay very fast by Cherenkov analogue effect due to neutral current interactions[5]. ICARUS collaboration, another team at Gran Sasso, had reported that superluminal CNGS neutrinos do not decay as theoretically expected [6] questioning OPERA result. To my point of view this objection to OPERA results is not valid because is based in a relativistic model, that will be not longer valid if superluminal neutrinos do exist. It is the same as to said that Bohr atom is forbidden because of Larmor formula will make the electrons to radiate.

In a recent work [7], it has been proposed an explanation for early arrival by  $57.8ns$  of the neutrinos with respect to the speed of light coming from "long"  $10500ns$  LHC extractions. This could be explained by a shape deforming effect of the neutrino distribution function, with respect to the proton distribution function (PDF) due to the stimulated absorption. But in this work it was also probed that stimulated absorption can not explain the apparent earlier arrival of 20 neutrinos reported for "short"  $3ns$  LHC extractions. The objective of this work is to probe that the shape deforming effect due to spontaneous emission produces a backward shift in time of  $65.8ns$  theoretically calculated on the basis of special relativity LASER equations. That is in agreement with the reported result.

## II. THE EXPERIMENT

First of all it is necessary to outline the experiment. The proton beam is produced with the CERN Super Proton Synchrotron (SPS), these protons are ejected with a kicker magnet, in two extractions each lasting  $10.5\mu s$  and separated by  $50ms$  towards a graphite target where billions of mesons are produced. These mesons are focused into a  $1km$  vacuum tunnel where the mesons decays into muons and neutrinos. Then neutrinos continue traveling through the inside of the earth by  $730km$  until they arrive to Gran Sasso Laboratory  $2.4ms$  later. Neutrinos are detected by OPERA in two separated groups: the first with mean neutrino energy of  $13,9GeV$  and the second with  $42,9GeV$ , corresponding to each one of the two proton extractions.

Proton extractions are similar to step functions with several peak or oscillations superposed. These peaks corresponds to the proton synchrotron radio frequencies of the SPS and the kicker magnet. The form of the time

distribution of proton function is accurately measured by a fast Beam Current Transformer (BCT) at center of the graphite target. The key of the experiment is that each maximum of the neutrinos detection must correspond to a maximum of the proton intensity.

To obtain the time traveling of the neutrinos, each of 16000 neutrino events detected were tag in time, and correlated with its corresponding proton time distribution function for each extraction with high accuracy. To do that, a probability density function (PDF) is constructed, summing up all the proton time distribution function, for which neutrino interactions were observed at the detector. Then this function is shifted in time ( $t \rightarrow t + TOF_c$ ) by the estimated time of flight ( $TOF_c = \frac{730.085km}{c}$ ) at the speed of light  $c$ . The peaks of these PDF function must correspond in time with the peaks in the neutrino detection if they fly exactly at the speed of light. The measured neutrino time distribution, detected at OPERA must have a delay time ( $t \rightarrow t + TOF_\nu$ ), corresponding to the time of flight of the neutrinos ( $TOF_\nu = \frac{730.085km}{v}$ ) at its real velocity  $v$ . As both time functions, the theoretical PDF function and the detected neutrinos distribution had been shifted by  $TOF_c$  and  $TOF_\nu$  respectively; the maximum likelihood analysis must gives the best fitting for a time lapse [1]:

$$\delta t = TOF_c - TOF_\nu$$

If this time lapse is positive means that the neutrinos arrived faster than expected for light, while if this quantity is negative means that the neutrinos are slower than light.

To obtain the average delay in time, between the neutrino detection and the PDF function, a numerical maximum likelihood analysis is performed. The results are shown separately for each of the the two extraction, that are enough separated by 50ms to be uncorrelated. The results are summarized in figure 1 taken from [1]:

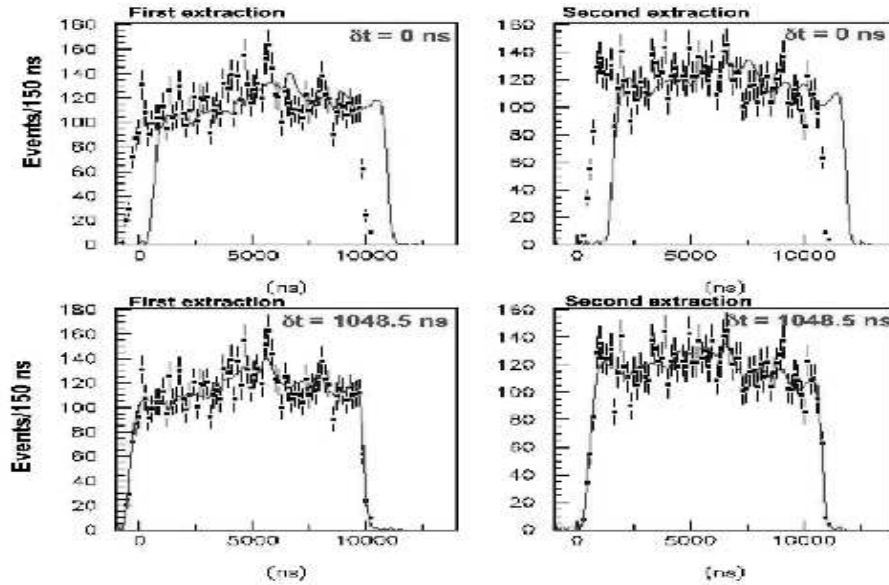


FIG. 1: Graphic of results of the PDF for protons and the detected neutrinos detected by OPERA

Surprisingly, a positive lapse shift of  $\delta t = 1048.5ns$  was obtained, indicating an early arrive than expected at the speed of light, there are corrections due to the electronic time tag GPS, UTC, BCT, etc that are summed up to  $(985.8 \pm 7.4)ns$ , when all the chain of systemic errors were taken into account. So, there is still an unexplained forward lapse shift of:

$$(57.8 \pm 7.8 \pm_{5.9}^{8.3})ns$$

that indicates that neutrinos are  $0.25 \times 10^{-4}$  faster than known speed of light in the vacuum. In this result had been included the statistical error  $\pm 6.9ns$  obtained from the maximum likelihood analysis, and checked with various combination of MonteCarlo simulations.

Recently the OPERA collaboration has reported 20 neutrino events obtained for very short proton extraction pulse, with a PDF gaussian mean width of only  $3ms$ , in four bunches separated  $524ns$  that is roughly one thousand times shorter than former long events. This 20 neutrinos also appears to precede light for

$$62.1 \pm 3.7ns \quad \text{with a RMS: } 16.4ns$$

These short extractions has a much lower particle density with only  $1.1 \times 10^{12}$  protons on target and mesons average lorentz factor as large as  $\gamma_\pi = 190$ . This result of only 20 events has a very high Root Mean Square of  $RMS := 16.4ns$ , so it will be significant only when taken jointly with the previous 16000 events result, but it has been used to discard the shape deformation factor as a possible explanation to the early neutrino arrival.

### III. DISCUSSION.

In a recent work [7], it has been proposed an explanation for the neutrinos coming from the "long"  $10500ns$  LHC extractions, that apparently arrives to Gran Sasso  $57.8ns$  earlier with respect to the speed of light in vacuum. That apparent early arrival could be explained by a shape deforming effect of the neutrino distribution function, with respect to the proton distribution function (PDF) due to the stimulated absorption while traveling by the decay tunnel that acts as a LASER tube, where other effects as stimulated emission, absorption and spontaneous emission could take place. In that work, it was obtained a shift factor for the maximum of the distribution functions is obtained, due to the combined stimulated absorption and emission effect:

$$\Delta t = (N_2 B_{21} - N_1 C_{12}) \sigma^2 \quad (1)$$

where  $N_2$  is the pion or meson density inside the decay tunnel,  $N_1$  is the muon density,  $B_{21}$  is Einstein [4] stimulated emission coefficient,  $C_{12}$  is stimulated absorption coefficient and  $\sigma$  the gaussian root mean square of the initial neutrino pulse.

When stimulated absorption dominates over emission, there is negative or backward shift in time for the maxima of the distribution functions while traveling through the  $L = 1km$  decay tunnel. If only stimulated absorption is considered (Beer-Lambert case,  $B_{21} = 0$ ) for the long pulse extractions, with  $N_1 \approx 10^{13}/vol$  (with a tunnel volume  $vol \approx 3000m^3$ ) taking  $\sigma \simeq 3300ns$  (that is also consistent with the tunnel length) with a stimulated absorption coefficient:

$$C_{12} \simeq 1.65 \times 10^{-6} \frac{m^3}{sec} = 5.49 \times 10^{13} barn \Rightarrow 2.79 barn/muon$$

will produce the  $\approx 60ns$  that had been reported by OPERA. But for the LHC  $\sigma = 3ns$  short pulse extractions, with a density of  $1.1 \times 10^{12}/vol$ , and the former  $C_{12}$  coefficient will give an insignificant time delay of

$$\Delta t = 0.0000015ns$$

As equation(1) is strongly dependent on  $\sigma^2$  that change for a factor of  $10^6$  (while density changes by an additional factor of 60) stimulated absorption or emission could not explain the early arrival of short and long CNGS beam simultaneously.

### IV. SPONTANEOUS EMISSION IN THE CONTEXT OF SPECIAL RELATIVITY

It is not know in which part of the  $1000m = 3300ns$  tunnel the decay of mesons into neutrino plus muon occurs, the statistical correlation of thousands of neutrino peak distribution against the PDF function will give the mean delay time with high statistical precision when it is assumed that the spatial distribution of the decays in the tunnel is random or gaussian, but it could happens that the starting point of neutrinos could be shifted in time or driven by stimulated or spontaneous emission-absorption processes, as happens for a pulse LASER traveling through an amplifier plasma with an initial population [3].

The balance equation considering spontaneous emission ( $A_{21}$  coefficient), stimulated emission ( $B_{21}$  coefficient) and stimulated absorption ( $C_{12}$  coefficient) proposed in [7]:

$$\frac{\partial n}{\partial t} + \frac{\partial n}{\partial x} \cdot \nu = N_2 A_{21} + N_2 B_{21} n - N_1 C_{12} n \quad (2)$$

$$\frac{\partial n}{\partial t} + \frac{\partial n}{\partial x} \cdot \nu = -\frac{\partial N_2}{\partial t} - \frac{\partial N_2}{\partial x} \cdot v_\pi \quad (3)$$

$$\frac{\partial n}{\partial t} + \frac{\partial n}{\partial x} \cdot \nu = \frac{\partial N_1}{\partial t} + \frac{\partial N_1}{\partial x} \cdot v_\mu \quad (4)$$

with neutrino density number  $n$ . The neutrino velocity is  $\nu$ , and the the meson and muon velocities are  $\nu_\pi$  and  $\nu_\mu$  respectively. All those densities are functions of the tunnel length  $x$  and the time  $t$ . For short  $\sigma = 3ns$  LHC pulse extractions the  $3300ns$  decay tunnel will be almost empty, so quadratic stimulated term could be a million times less than spontaneous emission process, so the system of equations reduces to:

$$\frac{\partial n}{\partial t} + \frac{\partial n}{\partial x} \cdot \nu = N_2 A_{21} \quad (5)$$

$$\frac{\partial N_2}{\partial t} + \frac{\partial N_2}{\partial x} \cdot v_\pi = -N_2 A_{21} \quad (6)$$

The second equation is Lorentz invariant, but the first is no exactly. That is due that for (6) the 4-divergence is taken for a 4-volume enclosed by the transverse area of the tunnel times a length equals  $\nu_\pi \cdot \tau$  and multiplied by a time interval equals  $\tau = (A_{21})^{-1}$  the mean decay life of the meson. Under a Lorentz transformation, the time length scales a Lorentz factor while the spatial length scale by the inverse of the Lorentz factor then the volume in which is taken (6) is invariant. But for equation (5), the volume length equals  $\nu \cdot \tau$ , where the speed of neutrinos is involved instead of that of the mesons, also the time interval to be taken is  $\tau = (A_{21})^{-1}$ , where the mean decay time life is measured in the rest or Lab system and not as seen from the meson. To correct this difference in the volumes in which particles are destroyed or created a factor of  $v/v_\pi$  must be included but at the rest or Lab system this factor is almost one:  $N_2 A_{21} \cdot v/v_\pi \simeq N_2 A$ , but equation (5) is valid only in the Lab system reference frame.

So in order to get the correct solution to the process we must go to the meson reference frame where  $v_\pi = 0$  and

$$\nu \rightarrow c'_v = \frac{\nu - \nu_\pi}{1 - \frac{\nu \nu_\pi}{c^2}}$$

then the equation system is:

$$\frac{\partial n'}{\partial t'} + \frac{\partial n'}{\partial x'} c'_v = \frac{N'_2}{\tau_o} \quad (7)$$

$$\frac{\partial N'_2}{\partial t'} = -\frac{N'_2}{\tau_o} \quad (8)$$

where  $\tau_o = 26ns$  is the mean life of the Pion in the meson reference frame.

Equation (8) could be easily integrated

$$N'_2 = N'_{20}(x') \exp\left(-\frac{t'}{\tau_o}\right) \quad (9)$$

$$N'_2 = N'_{20} \exp\left(-\frac{(x'/\nu_\pi)^2}{2\sigma_o^2}\right) \exp\left(-\frac{t'}{\tau_o}\right) \quad (10)$$

where a gaussian shape as in [7] was used and  $\sigma_o$  is in the meson reference frame. Equation (7) could also be integrated in term of the error function, but is easier to boost back to the Lab reference frame.

$$\frac{x'}{\nu_\pi} \rightarrow \left(\frac{x}{\nu_\pi} - t\right) \gamma_\pi = -\xi_\pi \gamma_\pi \approx -\xi \gamma_\pi \quad (11)$$

$$t' \rightarrow (t - \nu_\pi x) \gamma_\pi = \frac{1}{2} [\xi_\pi \gamma_\pi (1 + \nu_\pi^2) + \frac{\eta_\pi}{\gamma_\pi}] \approx \xi \gamma_\pi + \frac{\eta}{2\gamma_\pi} \quad (12)$$

$$\eta_\pi = t + \frac{x}{\nu_\pi}, \quad \eta = t + x, \quad (13)$$

$$\xi_\pi = t - \frac{x}{\nu_\pi}, \quad \xi = t - x \quad (14)$$

where the approximation  $v_\pi^2 \approx 1$  has been used at right hand equations. Then the solution to (7) and (8) could be written in the Lab Reference frame as a function of light coordinates  $(\eta, \xi)$  instead of the more exact characteristic coordinates  $(\eta_\pi, \xi_\pi)$

$$N_2 = N_{20} \exp(-\frac{\xi^2}{2\sigma^2}) \exp(-\frac{\eta}{2\tau}) \exp(-\frac{\xi\gamma_\pi}{\tau_o}) \quad (15)$$

$$n = N_{20} \exp(-\frac{\xi^2}{2\sigma^2}) \exp(-\frac{\xi\gamma_\pi}{\tau_o}) [1 - \exp(-\frac{\eta}{2\tau})] \quad (16)$$

where  $\sigma = \sigma_o/\gamma_\pi$  and  $\tau = \gamma_\pi \tau_o$  are in reference to the Lab Frame.

Proceeding as in [7] looking for the maximum:

$$\frac{\partial n}{\partial t} = \frac{\partial n}{\partial \xi} + \frac{\partial n}{\partial \eta} = 0 \quad (17)$$

$$0 = \left[ \left( -\frac{\xi}{\sigma^2} - \frac{\gamma_\pi}{\tau_o} \right) [1 - \exp(-\frac{\eta}{2\tau})] + \frac{1}{2\tau} \exp(-\frac{\eta}{2\tau}) \right]_{(t_2, L)} \quad (18)$$

then, valuating at the tunnel's end  $[\xi]_{(t_2, L)} = \Delta t = t_2 - t_1$  and  $[\eta]_{(t_2, L)} = \Delta t + 2L/c$  where  $L = 1km$  and  $c = 3 \times 10^5 km/s$ . Equation (18) could be rewritten as:

$$\frac{1}{2\tau} = \left( \frac{\Delta t}{\sigma^2} + \frac{\gamma_\pi}{\tau_o} \right) \exp[\frac{\Delta t}{2\tau}] (1 + \exp[\frac{L}{\tau c}]) \quad (19)$$

taking into account that  $\Delta t \approx -60ns \ll 2\tau = 9880ns$ , then  $\exp[\frac{\Delta t}{2\tau}] \approx 1$  in order to solve the transcendent equation (19) using that  $(1 + \exp[\frac{L}{\tau c}]) \approx 2.95$  equation (19) could be solved by

$$\Delta t = -\frac{\gamma_\pi \sigma^2}{\tau_o} + \frac{\sigma^2}{5.9\gamma_\pi \tau_o} = -65.8ns + 0.0003ns \quad (20)$$

As the forward time shift, for the 20 short pulse neutrinos obtained for OPERA is  $-62.1 \pm 3.7ns$ , the theoretical obtained  $\Delta t = -65.8ns$  completely explain it. This striking result make us to ask, if also the  $57.8ns$  early arrival for the "long"  $10500ns$  pulse extractions event could be explained by the  $200Mhz$  LHC harmonic, that is superposed to the long pulse with a period of  $T = 5ns$ , as could be seen in the following picture taken from [1].

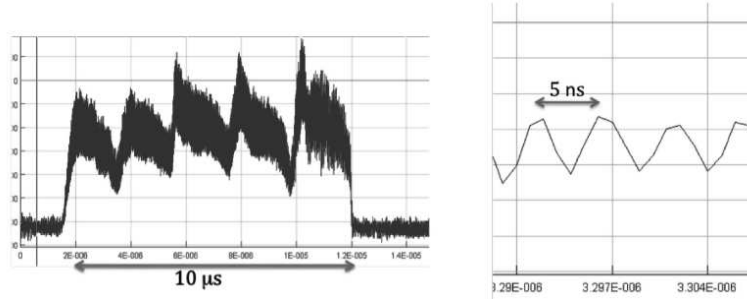


FIG. 2: Graphic of results of the PDF for the protons from LHC showing the 200Mz harmonic.

If we approximate this harmonic in the interval  $[-\frac{T}{2}, \frac{T}{2}]$  by a gaussian function

$$\frac{1}{2} (1 + \cos \frac{2\pi \hat{t}}{T}) \approx \exp(-\frac{\hat{t}^2}{2\hat{\sigma}^2})$$

for  $\hat{t} = \hat{\sigma}$  we get:  $\hat{\sigma} = 1.08ns$  that is enough to explain a early arrival of only

$$\Delta \hat{t} = -\frac{\gamma_\pi \hat{\sigma}^2}{\tau_o} = -7.3ns$$

So apparently, spontaneous emission only, could not explain the early arrival of long CNGS pulses, but as was done in [7] the remaining  $50ns$  could be fully explained if stimulated absorption (and possible stimulated emission) is taken into account.

## V. CONCLUSIONS

In conclusion the deformation of the  $\sigma = 3ns$  short pulses of neutrinos, calculated with relativistic corrections, produce an "apparent" earlier arrival of the neutrinos, with respect to the speed of light by

$$\Delta t = -\frac{\gamma_{\pi}\sigma^2}{\tau_o} = -65.8ns$$

explaining the reported earlier arrival of  $-62.1 \pm 3.7ns$  completely. So the short pulse neutrinos are not superluminal, there is a relativistic time shift that produce a deformation of the wave distribution function that shift the maximum, so it will arrive earlier, not real particles. Here is a clear prediction: the time shift for short pulses will be linear in the Lorentz factor and quadratic in the mean gaussian width  $\sigma$  that could easily tested at OPERA with the actual infrastructure.

As a second conclusion, the spontaneous emission process alone could not explain the  $-57.8ns$ . But it could be fully explained if stimulated absorption-emission processes were taken into account. The calculation performed in [7] is a very simple and restricted approximation, exact solutions of (2)(3) and (4) that takes into account relativistic correct volumes and real pion, muon and neutrino velocities are required.

There is a way to probe the existence of these shape deformation processes: to compare the detected neutrino time distribution with the muon probability distribution function, instead of the meson probability distribution function, because as the muon and the neutrino are created at the same event: they must have the same forward time shift so there, must be not difference in time at which intensities maximum are achieved. In [1] the muon PDF was not considered, because the simulations show that will give null corrections. That is not true as was shown in this paper. Muon PDF may be difficult to analyze because the muon is a very interactive charged particle, but comparison of muons PDF with detected neutrinos must be performed in order to establishes if neutrinos travel faster than light or stimulated absorption or emission of neutrinos exist.

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